

Experimental Results From the Thermal Energy Storage-1 (TES-1) Flight Experiment

The Thermal Energy Storage (TES) experiments are designed to provide data to help researchers understand the long-duration microgravity behavior of thermal energy storage fluoride salts that undergo repeated melting and freezing. Such data, which have never been obtained before, have direct application to space-based solar dynamic power systems. These power systems will store solar energy in a thermal energy salt, such as lithium fluoride (LiF) or a eutectic of lithium fluoride/calcium difluoride (LiF-CaF₂) (which melts at a lower temperature). The energy will be stored as the latent heat of fusion when the salt is melted by absorbing solar thermal energy. The stored energy will then be extracted during the shade portion of the orbit, enabling the solar dynamic power system to provide constant electrical power over the entire orbit.

Analytical computer codes have been developed to predict the performance of a space-based solar dynamic power system. However, the analytical predictions must be verified experimentally before the analytical results can be used for future space power design applications. Four TES flight experiments will be used to obtain the needed experimental data. This article focuses on the flight results from the first experiment, TES-1, in comparison to the predicted results from the Thermal Energy Storage Simulation (TESSIM) analytical computer code.

Developed by Dr. David Jacqmin of the NASA Lewis Research Center's Internal Fluid Mechanics Division, TESSIM can predict the migration of voids and the resulting thermal behavior of solar dynamic receiver canisters. It is currently useful as a qualitative design tool but requires further experimental validation before it can be reliably used for critical design decisions. Once thoroughly validated, the code will be invaluable in the detailed design of lighter, more efficient solar dynamic receivers.

An advanced solar dynamic power system with either a Brayton or Stirling Power Conversion System has the potential for high efficiency with lower weight, cost, and area than other solar power systems. When operating in a low Earth orbit, the power system will experience a sun/shade cycle on the order of 60-min sun and 34-min shade. Delivery of continuous electric power over the entire orbit requires a method of storing energy during the sun cycle for use during the shade cycle.

An efficient method of accomplishing this is to utilize the high heat-of-fusion associated with TES phase-change materials. These materials possess physical properties that are desirable in advanced solar dynamic heat receiver designs--including high heat-of-fusion, very low toxicity, and general compatibility with containment materials in a vacuum environment. However, they also have low thermal conductivity, low density, and most significantly, high specific-volume change with phase change. This last characteristic leads to the formation of a void, or voids, that can degrade heat-receiver energy transfer

performance by forming local hot spots on the container wall or by distorting the wall locally. Because the formation and location of voids are strongly influenced by gravitational forces, it is necessary to be able to understand and predict this phenomenon in the on-orbit microgravity environment in order to achieve the optimum design for the heat receiver canisters. This is especially important since the canister and heat receiver are significant elements of the overall weight and cost of a solar dynamic power system.

Four experiments are needed to provide the data necessary to validate the TESSIM code. The first two flight experiments, TES-1 and TES-2, were developed to obtain data on TES material behavior in cylindrical canisters. These experiments are identical except for the fluoride salts characterized. TES-1 used lithium fluoride (LiF) salt, which melts at 1121 K; and TES-2 will use a fluoride eutectic salt (LiF/CaF₂), which melts at 1042 K. A postflight tomographic scan of each TES canister will provide data on void location, size, and distribution for comparison with TESSIM predictions.

From the data collected on orbit, the first figure shows some erratic behavior in the first melt cycle in comparison to the remaining three melt-freeze cycles. We believed this to be caused by migration of the void and/or by the gravitational forces present during this period. In general, after the first melt-freeze cycle, the temperatures show repeatability from cycle to cycle at each location.

After the experiment, the canister was scanned by Computer-Aided Tomography (CAT) to record the final location and distribution of the voids in the canister. The second figure (ref. 1) shows the tomographic data taken on the TES-1 canister for nine stations along the length of the canister, along with the predicted results from TESSIM. Salt locations are shown in black. In general, TESSIM appears to have predicted void behavior accurately, as is evidenced by comparing the tomographic images with the TESSIM images. These initial results from TES-1, of high-temperature fluoride salt melting and freezing under microgravity, do not absolutely validate TESSIM, but the comparison of the predictions with the data establishes a basic confidence in the code. Future experiments, such as TES-2, -3, and -4 will help to further validate TESSIM.

The TES-1 flight experiment provided the first experimental data on the long-duration effects on TES salts used for space-based solar dynamic power systems. Good correlation between the predicted on-orbit characteristics of the salt and the actual flight data indicate that, for the configuration tested, the TESSIM code is basically sound. The additional three flight experiments will provide the opportunity for the TESSIM code to be validated completely. The flight experiments will provide data from different canister configurations and both wetting and nonwetting interfaces for the TES salts. In addition, the effect of heat leakage will be studied more closely.